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# ON THE ELECTRICAL EXCITABILITY OF THE SKIN.

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THE object of the following pages is threefold. First, to indicate the conditions which any rational method must fulfil which pretends to give us accurate results as to the electrical excitability of the cutaneous nerves; these conditions will be found to depend partly upon the behaviour of the electrical current, partly upon certain anatomical peculiarities of the skin. Secondly, to criticise in the light of the principles set forth the chief methods hitherto proposed to estimate the electrical sensibility. Third, to propose a new method more simple and rational; and state some of the results already obtained from its application.

## I.

According to the general law of excitation of nerves, formulated by Du Bois-Reymond, this excitation depends upon the *rapidity* with which the electrical density changes in the nerve, and not with the *absolute value* of that change.

Hence we ought, for measuring the electrical excitability of a nerve, to determine the rapidity of change in the density necessary to excite it; and this is what Dr. v. Fleischl's[1] ingenious instrument, the Rheonome, enables us to do. Only

[1] "Untersuchung über die Gesetze der Nervenerregung," III. Abhandlung. Stżber. d. k. Academie der Wissensch. zu Wien. Vol. lxxvi., Part III., p. 138.

such measurements are much too complex to be of any practical clinical value. It is, however, possible to attain the same object by simpler means, through the elimination of some of the variables in the experiment. Thus if the current is made through the nerve with always the same rapidity, so that it reaches its maximum intensity in the same space of time, we may measure the excitability of the nerve by the density of the current flowing through it. Or again, if the diameter of the nerve remains constant, its excitability may be estimated by the strength (intensity) of the current.

It is easy to base upon these considerations a rational method for measuring the electrical excitability of the skin. This would consist in giving the galvanometric value of the currents necessary to produce the minimum sensation in every part of the skin; provided that these two conditions are observed: (1) the make and break of the current must be made every time with the same rapidity; (2) the surface of contact of the electrode with the skin must always be the same. It is evident that by using this method we are independent of all the variations in the resistance, permanent or incidental, originating in the parts to be examined. Let it be clearly understood, however, that we assume here a direct galvanometric measurement of the current strength, and not an estimation of it by resistances introduced either in the circuit itself, or in a derived current.[1]

Given two points of the skin of different electrical resistance; we must, to obtain the same current-strength in both cases, use a different number of elements. Once the same current-strength obtained, the excitation is the same in both cases, provided always the other conditions be fulfilled, i.e. equal rapidity of make and break, and equal extent of excited surface. Now it is clear that under such circumstances, if the excitability be the same, the effect of the excitation must be the same also.

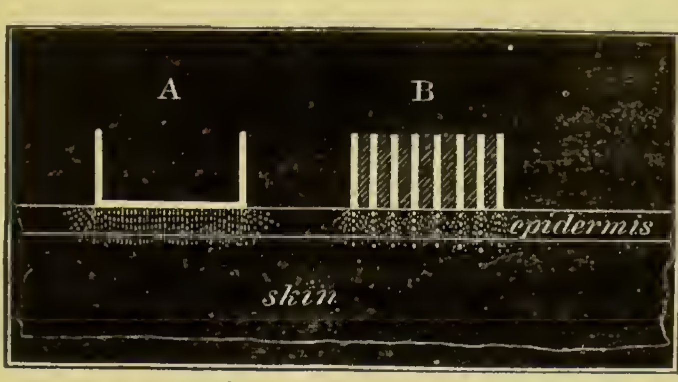
By these means, then, we are made independent of the source of error pointed out frequently before and arising from

[1] The latter process, so often employed by electrotherapeutists, after the example of Brenner, ought to be entirely abandoned. Applied in researches such as those we have described, for instance, it would give entirely erroneous results.

the variable thickness of the epidermis. Yet, in order to be able to measure the excitability, not of the collective nervous elements of the skin, but of the cutaneous nerves themselves, we must be able to eliminate the sources of variation arising from the structural differences of the nervous supply in different parts of the skin.

We have, it is true, no direct anatomical demonstration of such differences; but physiological observations, such as the measurements with E. H. Weber's compasses, allow us to suppose that the number of nervous endings in a unit of cutaneous surface varies in different parts of the body. If this supposition be true, it necessarily follows that an electrode of the same surface applied to different parts of the body ought to produce excitations of various strengths merely on account of the variable richness of the skin in nerve-endings.

The way to eliminate this source of error consists in always exciting the skin at the same number of points by means of a special form of electrode. The simplest would be a pointed electrode which would eliminate the influence of a variable number of excitations by reducing this number to a minimum; but its sharpness would make an accurate estimation of the minimal electrical excitation difficult. The following form of electrode, however, satisfies the present condition sufficiently well: It consists in a small cylindrical bundle of well insulated wires; and it is not difficult to understand the important difference between the effects of such an electrode and those of one in the shape of a solid cylinder of the same diameter.




The figure makes this difference evident. The excitation produced by B will be stronger than that produced by A

because the surface of the metallic contact with the skin is less, and hence the density of the current greater. Again, and this is the important point, the number of the excitations in the case of B will be more uniformly the same, whilst in the case of A it will depend upon the abundance of cutaneous nerve-endings. For it may be assumed that, with B, none but the shortest currents from the wires through the epidermis will stimulate the nerves; that is, none but the nerve-fibres lying nearest to the wires (the points of greatest electrical density) will be stimulated—especially as we here deal merely with minimal excitations. We shall see further on that experience has completely borne out these theoretical considerations.

There is yet a condition that has not hitherto been attended to in testing the sensibility of the skin, and which must however, have some influence on the results of the experiments. One of us (Dr. Tschiriew) in a paper forthcoming in the *Archives de Physiologie* (Charcot, Vulpian, and Brown-Séquard) starting from physiological and pathological data, shows that it is necessary to assume the interruption of all the centripetal paths in the grey matter of the spinal cord; and that the differences in the duration and intensity of the excitation necessary to produce the same effect may be explained by the variations occurring in that interruption among the several afferent nerves. Hence it follows that, in order to eliminate differences due to any such variations possible among the afferent cutaneous nerves, it is necessary to allow a certain duration to each excitation.

In order to fulfil this condition if the continuous current were used, and also to avoid the mechanical and electrotonic influences of this current upon the tissues, we should require an apparatus which would interrupt the current, and at the same time reverse it each time, at a uniform rate of speed. This obviously complicates the process so much as to make it inapplicable for clinical observation. But before we pass to the description of a simpler and more practical method we must say a few words on those hitherto proposed, and examine how far they fulfil the conditions just laid down.

## II.

In 1864 Munk and Leyden ('Untersuchungen über die Sensibilität im gesunden und kranken Zustande,' Virchow's 'Archiv,' vol. xxxi. page 1) described the following method for testing the electro-cutaneous sensibility. A pair of wooden compasses were fitted with metallic terminations connected with the secondary coil of a Du Bois-Reymond's induction apparatus. The points were fixed at a constant distance from one another (1 cm.), and applied to the skin. The sensibility was then determined by noting the distance between the two coils when the point of minimum sensation was reached. Simple make or break induced currents, of constantly the same rapidity, were used. This method led its authors to the following results: (1) Different regions of the skin differ in their absolute sensibility in much the same degree as in their sense of space (Weber).[1] (2) The electro-cutaneous sensibility decreases in the following order: face, trunk, upper arm and thigh, elbow and knee, tips of fingers and toes.

The authors themselves define the value of these measurements by adding that the local thickness of the epidermis, as well as the local abundance of nerve fibres, must influence the results obtained. This method is indeed faultless if our object is merely to determine the electro-sensibility of the skin as a whole, with all its incidental peculiarities, such as the varying thickness of its epidermis, abundance of its sensitive elements, conductivity of its subjacent structures, and mode of interruption of its afferent nerves in the spinal cord. For it is admissible that in every healthy individual the *distribution* of these anatomical peculiarities of the skin in its different parts follows the same law. On the other hand it would be impossible to draw any conclusions whatever from results obtained by this method about the sensibility of the cutaneous nervous elements themselves, since these results have been obviously modified by the various conditions just enumerated.

[1] This hardly agrees with the results obtained by the authors themselves: the tips of the fingers, for instance, are more developed for the sense of space than the trunk.

Bernhardt ('Electrotherapeutische Notizen,' Deutsches Archiv für Klinische Medicin, 1877, vol. xix. p. 382), whilst objecting to the foregoing, the practical difficulties in the comparison of results obtained with different induction apparatus, proposes the following method: to measure the electrocutaneous sensibility by the resistances which must be intercalated in a derived circuit in order to reach the minimum sense of pain. The "modus operandi" is as follows: The patient holds the positive electrode of a battery of thirty Stöhrer's elements in his left hand. The sensibility is tested by means of a wire brush connected with the negative pole. A derived current is established through a rheostat, and the resistances read off as soon as pain is experienced. These readings give the measure of the sensibility.

This method offers no advantage over that of Munk-Leyden; the results obtained even for the same individual are hardly comparable among themselves. The relations between the variations in the rheostat resistances and the current strengths thus set up through the body, are obviously far more complex than those between the distances of the coils and the strength of the induced currents in a non-graduated apparatus. Besides, given the number of cells included in the inducing circuit, and the number of turns of wire in both coils, the true value of the distances between the two coils noted in any experiment can at any time be ascertained; whereas the value of the rheostat resistances could be determined only by the repetition of all the measurements upon the same person, and by a process the complexity of which is in itself greater than the graduation of an induction apparatus.

Again the determination of the minimum sensation obtained on exciting by a single make or break of a continuous current, owing either to the longer time it takes to attain its maximum intensity or to the electrotonic influences it exerts upon the tissues, is much less precise than that produced by the induced current. This is easy to demonstrate upon oneself. The matter becomes of still greater importance when we have to do with patients whose intelligence is not always of the keenest. We may also recall the well-known phenomenon explainable by the electrotonic effects of the galvanic current:

that, when we think we have reached the minimum current strength that will produce sensation, we find, on controlling the experiment by further diminishing the current, sensation will now manifest itself to much weaker stimulations than at first.

But the greatest objection to Bernhardt's method is the fact that the resistance of the body included in the circuit varies with every new position of the negative electrode—a source of errror which he gives us no means to remedy. As an instance of the results he obtains we may quote the following measurements: for the tip of the nose, from 50 to 60 Siemens' units,[1] intercalated resistance sufficed; whereas 2000 to 3000 S. U. were necessary for the tips of the fingers and toes! As to the general conclusions reached by the author, they agree with those of Munk and Leyden. He, too, refrains from drawing any as to the irritability of the cutaneous nerves themselves.

The current number of the 'Archiv für Psychiatrie' contains a paper by Drosdoff ('Untersuchungen über die electrische Reizbarkeit der Haut bei Gesunden und Kranken,' vol. ix. part 2). The highly elaborate form in which these researches are presented, compels us to pay more attention to them than their intrinsic value deserves. Some of the objections raised by the writer to the previous methods are either utterly groundless or have been anticipated by their authors themselves. Thus, for instance, when he objects that the results obtained by Munk and Leyden are vitiated by the varying abundance of nerve elements in the skin, he forgets that, so far from falling into such an error, these authors had pointed out this fact as forbidding them to conclude from the sensibility of "the skin" to that of "the cutaneous nerves." This does not prevent Dr. Drosdoff from falling into it himself; though judged from his own standpoint, the method he uses is still more defective than that of the above-named authors. Like Bernhardt he fixes one of the electrodes on some part of the body (the sternum), and explores the sensibility by means of the other electrode in the shape of a wire brush. He uses a non-graduated induction apparatus, and estimates the sensibility by the distance

[1] Siemens' unit of resistance is equal to ·97 ohm nearly.

between the two coils, like Munk and Leyden. This method is thus merely a combination of the two former ones, from the imperfections of which it does not escape. It unites the limited applicability of the first (Munk-Leyden) to the weakest point of the second (Bernhardt), in that it introduces a different resistance into the circuit, with every change of position of the exciting electrode. Neither do the results obtained by Drosdoff differ materially from those of the previous observers. In order, however, to find out whether the differences in the sensibility discovered in different parts of the body are not simply due to differences in the resistance of these parts, the author has made numerous measurements of what he calls "epidermic resistances." For this purpose he fixes one of the electrodes of a battery of twelve Stöhrer's elements on the sternum, and applies the other to the various parts of the body, the sensibility of which has been tested. A galvanometer with 150 turns of wire is introduced in the circuit, by the readings of which the resistances are estimated. Now it is evident that it was the resistance of the whole portion of the body included between the electrodes ard not that of the epidermis that the author was measuring. Again, if the instrument used was a simple sinus-galvanometer, and was not graduated in absolute units—and he says not a word on this important point—it is evident that his measurements did not correspond to the absolute value of the electrical forces. As it is, one is struck at first sight by the parallelism between the series of numbers obtained by the resistance-measurements and those obtained by the sensibility-measurements at different points of the body; but, strange to say, the author draws from them the following conclusion: that there is no relation between the differences of resistance and of sensibility of the same points. Let the reader judge for himself. At page 213, under the title of "electrical zones," we find the following numbers:

| | | | | | | |
|---|---|---|---|---|---|---|
| M.S. . . | 232·5 | 212·0 | 200·7 | 193·3 | 154·2 | 188·1 |
| M.P. . . | 165·2 | 156·5 | 146·4 | 142·3 | 123·6 | 142·3 |
| Dev. . . | 22·2° | 9·3° | 6·9° | 4·5° | 2·5° | 6·5° |

And at page 215:

| | | | | | | |
|---|---|---|---|---|---|---|
| M.S. . . | 184·6 | 184·2 | 178·1 | 138·8 | | |
| M.P. . . | 143·0 | 140·0 | 133·0 | 117·6 | | |
| Dev. . . | 7·1° | 5·3° | .3·4° | 2·9° | | |

M.S. stands for minimum sensation; M.P. for minimum pain; Dev. for deviation in degrees of the needle. Each vertical column of numbers corresponds to one of the author's zones. These numbers are means of ten observations, and therefore have a higher intrinsic value than each of their component factors. The parallelism which we observe among them is quite as marked as what we could expect from the imperfect method used and the peculiarities of human bodies.

The way Dr. Drosdoff escapes the conclusions forced upon him by his own data is to pick out among the individual factors a few exceptional numbers in which the parallelism does not exist; and from these exceptions, due probably to unavoidable errors of observation, he concludes that there is on such thing as a relation between the variations of the resistance and of the sensibility. Further, upon this extraordinary conclusion, the author bases another assertion of still higher import, and which he gives as the grand result of his investigation, viz.: "that the differences of sensibility at different points of the skin are due to differences in the excitability of the nerves themselves." We shall state evidence further on to disprove the author's conclusions, from the results of our own experiments. They are far from being deducible from his own measurements, and indeed it would seem that he has conspicuously brought into evidence the great influence variations of resistance have exerted upon the results obtained. Elsewhere he is led astray by his ignorance of the properties of the instruments he used. He says (page 219), "The difference ('Verhältniss') between the minima of sensation and those of pain varies between 6 and 88 mm. (mean: 11–73.6) distance between the two coils. These distances diminish, in the case of painful impressions, with the increase of current strength." This statement is false if by it is meant that there

is any relation between the two kinds of sensation; for the author's results have been obtained with a non-graduated apparatus, and is ascribable to the mere absence of proportionality between the distances of the coils and the strengths of the corresponding currents.

## III.

From what we have said, it is clear that the method of Munk-Leyden is sufficient for measuring the sensibility of the skin; and that none of the methods hitherto proposed enables us to test the electrical excitability, absolute or relative, of the cutaneous nerves themselves.

We have pointed out previously a rational method for accomplishing this object. But, as we saw, though correct, it is too complex to be applicable to clinical purposes. We have, however, another one to propose, which is simple, though fulfilling all the conditions which have been laid down previously. We now pass to the description of this method, and of the results we have been able to obtain by its application.

Its principles are the following: (1) Elimination of all the sources of variation in the strength of the currents due to the variable thickness of the epidermis,[1] and the different positions of the electrodes, &c., by intercalating in the circuit such resistances as to make such variations insignificant; (2) Elimination of the influence of the variable abundance of nervous elements in the skin by exciting it at a constant number of points disposed over a constant surface. The latter is effected by using the form of electrode described previously, and composed of a solid cylinder of insulated wires.

In order to fulfil the first condition, it was necessary to know what resistances the human body could offer in such experiments. The measurement of these resistances is far from being such a simple process as is commonly thought. The conditions of experimentation from which they are ob-

[1] This condition has often been held up as very unfavourable to the appreciation of the sensibility of the cutaneous nerves, and it is thought that were that thickness known at various parts of the body much could be gained thereby. We hold the opposite view; for if we cannot eliminate by the method itself the influence of the epidermis, how can we hope to be able to do so by calculation when we are acquainted, ever so precisely, with its thickness at every part of the body?

tainable are so various as to make it impossible to speak absolutely of the electrical resistance of a part of the body, but only of its resistance under this, that, or the other condition. For instance, according to the details of the process of experimentation adopted, the "resistance of the forearm" may vary from about two to forty (or more) thousand ohms. The main circumstances influencing the results are: (1) the size, shape, and moisture of the electrodes; (2) the pressure with which they are applied; (3) the strength of the currents employed; (4) the condition of the parts tested, e.g. the degree moisture of the epidermis, the previous application of a more or less strong current, &c.

The first circumstance is of easy explanation. The fact that resistance diminishes with the pressure exerted upon the electrode is not so satisfactorily accounted for. It is more readily observed in parts of the skin with a compressible, rather than a hard, subjacent tissue. The electrical resistance may be diminished, on increasing the pressure, by one-half, two-thirds, or even more.

The variations dependent upon the current strength are illustrated by the well-known fact that when first applied to the skin a current from a large number of elements may be weak, but soon becomes stronger, showing that the patient's resistance diminishes. This diminution must be, partially at least, explained by the cataphorical effect of the current (du Bois-Reymond) by which liquids are conveyed into the integuments either from the electrode or from the subjacent tissues. Hence weak currents must be used for measurements in order to eliminate this source of error. The fourth condition referred to above may also be reduced to the increased moisture of the integuments. The following experiment will illustrate it. An electrode is fixed to the back, and another applied to the dorsal surface of the forearm. The resistance is found to be about 10,000 ohms. After a little rubbing of the arm with the electrode, and a strong current, the resistance is found to have sunk below 3000 ohms. The practical outcome of all this for measurements of body-resistances is that, first, all the conditions of observation must remain the same throughout; second, all these conditions must be carefully described in

every case. If these requisites are not fulfilled, the data obtained cannot have the slightest value.

Our measurements were taken as follows: A metallic plate, 5 × 12 cm., covered with wet wash-leather, was fixed to the upper part of the back; the various parts of the body were explored with a metallic disk 7 mm. in diameter, also enclosed in wet wash-leather. The latter electrode was fixed to an Eulenburg's baræsthesiometer, in order to ensure the same amount of pressure everywhere. The pressure used was of 150 grammes. The skin at the point of application was moistened, and the time taken for each observation restricted to a few seconds, in order to avoid differences arising to the unequal imbibition of the epidermis. Several observations were taken for each region, but the electrode was never re-applied to exactly the same spot, or only so after some time had elapsed. The battery used was a Gaiffe-Leclanché, and the number of elements used (4-14) chosen so as to obtain at every part a weak current (.2 to .5 milliveber),[1] and to avoid the disturbing effect of strong currents on the tissues. The following table gives our own resistances in ohms:

| | Ohms. | Ohms. |
|---|---|---|
| Tip of nose | 12,000 | 8,100 |
| Forehead | 4,000 | 3,000 |
| Cheek | 8,200 | 6,400 |
| Forearm (post) | 18,750 | 14,000 |
| „ (anter.) | 20,000 | .. |
| Hand (dorsal) | 21,000 | 15,500 |
| „ (palmar) | 42,000 | 48,000 |
| Tips of fingers | 65,000 | 46,000 |
| Leg | 21,000 | 23,000 |
| Foot (dorsum) | 22,000 | 24,600 |
| „ (sole) | 80,000 | 50,000 |
| Tips of toes | 60,000 | 60,000 |

[1] A current of one milliveber is that obtained with one volt through one thousand ohms. The electromotive force of a Daniell's cell is nearly one volt.

These numbers hold only for limited areas of the regions investigated. The different portions of the leg, for instance, tested under the same conditions throughout will vary in resistance according to the peculiarities of the epidermis and subjacent tissues. Similar measurements made with the electrode used in testing the sensibility (a cylindrical fasciculus of insulated wires) gave still more considerable differences, especially with the dry skin. In this way the resistances of the tips of the fingers and toes may amount to 100,000 ohms and more.

Hence we see that in order fully to eliminate the influence of the body-resistance in investigating the sensibility on Bernhardt's principle, at least a 2-million ohms' resistance is to be introduced in the circuit; and it is easy to perceive how much this author's and Drosdoff's results must have been influenced by these sources of fallacy which they have ignored.

For the investigation of the sensibility, our method consisted in fixing a large neutral plate-electrode on the back; and in using as differential or exciting electrode a metallic wire brush, of which the wires were insulated with sealing-wax, and brought together to form a cylindrical bundle of 75 mm. diameter. Care was taken that the exciting surface was as smooth as possible. This electrode was mounted on an interrupting handle. A Du Bois-Reymond's induction apparatus, fed by two Bunsen's cells, was used. The secondary coil (600 metres of 0·225 mm. copper wire) was used, and in the circuit included a resistance of upwards of three million ohms, formed by a slip of vulcanite overlaid with a film of plumbago. The hammer of the apparatus was made to vibrate at a rapid rate, and the current closed by means of the key through the previously applied electrode. This is a most important precaution, as "dabbing" the skin with the current on would produce such variations in the density of the current as to vitiate all the results. The minimum point of sensation was sought by adapting the distance between the two coils, whilst excitations were made by making and breaking the current by means of the key, the electrode remaining immoveable *in situ*. Finally, sufficient time was allowed for each excitation.

In this way we have arrived at very unexpected results.

In opposition to what has been stated by previous observers, we have found that *the electrical excitability of the skin, or rather of the nerves of the skin, is the same at every part of the body.* There always occur slight differences (amounting to from a few mm. to 1 cm. of coil); but on the one hand these differences are not always in the same sense, on the other their absolute value is too small [1] to claim any special signification.

Several points must be attended to in order to obtain reliable data with our method. (1) The elements feeding the coil must be *constant* (this excludes Leclanché's, and all single fluid cells, such as Stöhrer's, Smee's, &c.). We used two Bunsen's. (2) The conducting wires must be thoroughly insulated from every surrounding object, owing to the enormous "tension" [2] of the current. (3) As before mentioned, the excitation must begin after the electrode is *in situ.* (4) The portion of skin tested must be moistened. At first sight this last condition appears superfluous; for how, it is asked, can the hygrometric state of the skin have any influence when the circuit contains already such an enormous resistance?

We venture to offer the following explanation of this phenomenon. It is not due to any change in the resistance of the skin; because such a change would, as objected, be of no appreciable influence under the circumstances, and because also—a fact opposed to such a supposition—dry skin is more excitable than moist skin. But, as it has been experimentally shown (Tschiriew, 'Ueber die Nerven- und Muskelerregbarkeit,' in Du Bois-Reymond's Archiv f. Anat. & Phys., 1878, p. 494), electricity distributes itself, in a transverse section of every conductor it passes through, always in an inverse ratio to the resistance (Kirchoff's law), *independently of any resistance in the circuit.*

[1] Though the curve representing the relation between the distances of the two coils and the current-strengths corresponding to these distances is entirely independent of the resistances in the circuit of the secondary coil, the absolute value of these currents is *not* independent of these resistances, which appear in the curve as one of the parameters. Since then, in our experiments where the circuit included an intercalated resistance of several million ohms, the variations of 1 cm. or less in the coil-distances can correspond but to very small variations in the current-strengths.

[2] De Watteville, "On the Nature of Electrical Tension."—'Medical Times and Gazette,' Sept. 1877, and 'Med. Electricity,' Chap. I.

Hence even in our experiments where several million ohms' resistance was included in the circuit, even in the case of the dry skin where we must assume differences of resistance between the dry epidermis and the sudoriparous ducts, the whole current would find its way through the points of least resistance. Hence a current, which on a moist skin would have been hardly felt, may become even painful on a dry one. It is a well-known fact that the excitation of the dry skin produces a pungent sensation; of the moist skin a milder sensation—the latter being more evenly diffused than the former. Again, this difference is less marked in some regions than in others; for instance, less at the finger-tips than on the cheek or dorsum of hand. Hence appears the importance of eliminating this source of fallacy.

Another capital precaution in sensibility-testing is to avoid placing the electrode on any nervous twig. The peculiar sensation evoked will tell us if it has been done; and as a rule we must always choose the least sensitive spots for exciting. Generally speaking it will be advisable to avoid those spots where the epidermis is very thick; this latter condition would involve not only a higher resistance, but also a greater thickness of the layer interposed between the nervous elements and the electrode, and thus increase the diffusion of the currents before they reach the nerve-endings. In order to illustrate the influence of the kind of electrode we use (cylindrical bundle of insulated wires) in eliminating the influence of the variable abundance of cutaneous nerve-elements, we have compared its effects with those of a solid cylinder of the same diameter (7 mm.). With the former, as above related, we found the excitability of every part of the body practically the same. With the latter, we found it different, and to a certain extent varying in the same ratio as Weber's sense of space. Thus:

| | cm. | | cm. |
|---|---|---|---|
| Nose . . . . . | 7· | Hand (palm) . . . | 5· |
| Forehead . . . . | 7·2 | Tips of fingers . . | 8·3 |
| Lips . . . . . | 7·3 | Leg . . . . . | 3· |
| „ (red part) . . . | 5·3 | Foot (dorsum) . . . | 4· |
| Forearm (front) . . . | 6·6 | „ (sole) . . . | 0· |
| „ (back) . . . | 5·2 | Tips of toes . . . | 7·5 |
| Hand (back) . . . . | 5·5 | | |

In the interpretation of these data, however, it must be noted that we used a non-graduated induction apparatus, fed by two Leclanché's, with several million ohms' resistance in the circuit. We have seen before that the absolute strength of induced currents diminishes in an inverse ratio to the intercalated resistance. Hence the absolute value of the excitations corresponding to the coil-distances just given is much less than if the body alone had been included in the circuit.

The different results obtained from the use of the two forms of electrodes can be explained only by the fact of the varying nervous supply of different regions of the skin, and the elimination of its influence in the case of the special electrode.

Another observation we have made in the course of our experiments and which illustrates the importance of the shape of the electrode in exciting the skin, is, that if the bundle of insulated wires was made into an elliptical instead of a cylindrical column, the results obtained depended upon the relative position of its long axis with reference to the prevailing direction of the subcutaneous nerves. If the long axis coincides with this direction (as for instance in the limbs in the direction of their length) the excitation produced is less powerful than when it is transverse to the general course of the nerves. The same result is observable when a solid elliptical electrode is used.

This fact does not disprove our assertion about the possibility of eliminating the influence of the relative abundance of nerve-elements in different parts of the skin by our electrode. For, besides the arguments derived from comparative experiments, it is hardly possible to conceive such a regular distribution of nerve-endings in the skin that a mere alteration in the direction of the electrode should be followed by a change in the number of the endings influenced. We must assume, then, that we have here to do with a new factor of influence in the measurement of sensibility, viz., the mode of division and subdivision of the subcutaneous nerves.

An analogous phenomenon is observed with Weber's compasses. If at the same spot the minimum distance of distinct

impressions is sought in various directions, it is found (especially in the limbs) that these distances are greater in a parallel than in a transverse direction to the main course of subcutaneous nerves. Hence Weber's "circles" are ellipsoids with their long diameter directed along those nerves.

The explanation of this phenomenon is, that when the long axis of the electrode coincides with the main direction of the nerve-trunks, the larger number of exciting points influence the terminations of the same system of ultimate fibres of some one nervous twig. If, on the other hand, the long axis of the electrode is directed transversely to the nerves, the number of excited points of each twig will be less, but the number of those twigs stimulated will be greater.

Hence it will be observed that for testing the sensibility, electrodes with a circular surface of contact are alone to be used in order to eliminate this disturbing factor from the results.

The advantages of the method we have adopted are, that it is simple, easily applicable in clinical investigations,[1] and that its results, to be understood, do not require any comparison with tables of the distribution of sensibility in different parts of the body. As an example of its application we subjoin the results obtained in a case of bulbar paralysis with lateral sclerosis. All the tendon-reflexes were exaggerated, especially on the right side. The sense of touch was nowhere greatly impaired, but there was decided diminution of the sensation to pain, on the right side especially.

[1] In order to facilitate the application of our method, we are endeavouring to produce an appropriate electrode. Our present model is to consist of a tube of non-conducting material containing in its upper part a rod of resisting substance —kaolin and graphite—of two million ohms; in its lower, a cylinder of metal, the extremity of which forms the exciting surface. This surface will be subdivided by a system of intersecting grooves filled with an insulating substance, into a number of exciting points, as shown in the diagram already figured. This little appliance, mounted upon an ordinary interrupting handle, will be all that is required, besides an induction apparatus with a moderately long and fine secondary wire and a constant element.

| Part of Body. | Distances of Coils. | |
|---|---|---|
| | Right. | Left. |
| Nose . . . . . . . . . | 6· | 7·2 |
| Forehead . . . . . . . . . | 6·1 | 6·5 |
| Cheek . . . . . . . . . | 4·3 | 5·5 |
| Back (lower dorsal) . . . . . . . | 0·5 | 3·6 |
| Arm . . . . . . . . . | 4· | 5·6 |
| Forearm (back) . . . . . . . | 3·5 | 5·3 |
| „ (front) . . . . . . . | 3·7 | 4·5 |
| Hand (back) . . . . . . . . | 2·2 | 4·6 |
| „ (palm) . . . . . . . . | >0 | 0 |
| Tips of fingers . . . . . . . . | 3·2 | 5·5 |
| Leg . . . . . . . . . | 0 | 5· |
| Foot (dorsum) . . . . . . . . | 0 | 3·7 |
| „ . . . . . . . . . | >0 | 0 |
| Tips of toes . . . . . . . . | >0 | >0 |

The same induction apparatus as previously was used, with two Bunsen cells. In the circuit a resistance of more than three million ohms was intercalated.

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